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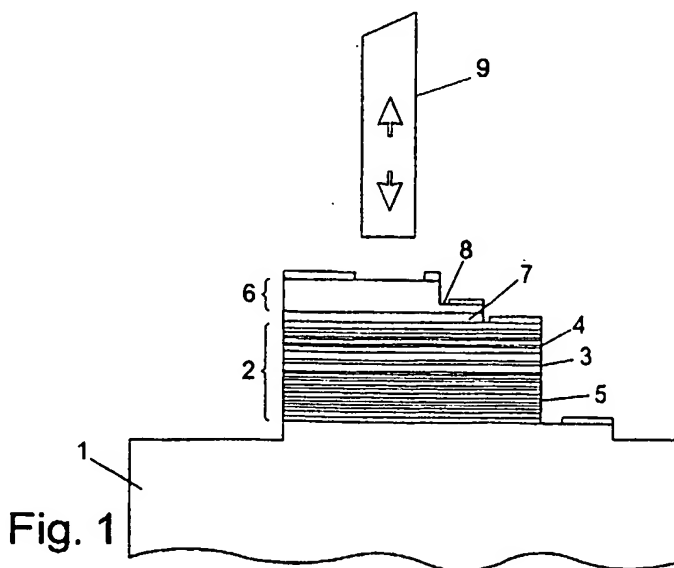
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(54) Abstract Title

**Vertically integrated optical transmitter and receiver**

(57) An optical transceiver having an integrated structure comprises a substrate 1, a VCSEL 2 on the substrate 1 to transmit an optical signal of a first wavelength in a first direction along an optical path, and a reception photodiode 6 integrated with the VCSEL 2 on the substrate 1 to detect an optical signal of a second wavelength, which is different to the first wavelength, travelling along the optical path in a second direction opposite to the first direction. The VCSEL 2 and the reception photodiode 6 are positioned in sequence along the optical path and one of the devices, for example the photodiode 6, is adapted to allow one of the optical signals to pass through it in its passage along the optical path. The fact that the two devices are integrated in this manner, either by being grown on a common substrate or by flip-chip bonding, means that such an optical transceiver is capable of bidirectional optical communication over a single optical fibre without requiring the use of additional optical components to increase coupling efficiency to the optical fibre. This renders further components on the substrate unnecessary, and enables the transceiver to be produced at very low cost.



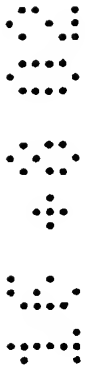


Fig. 1

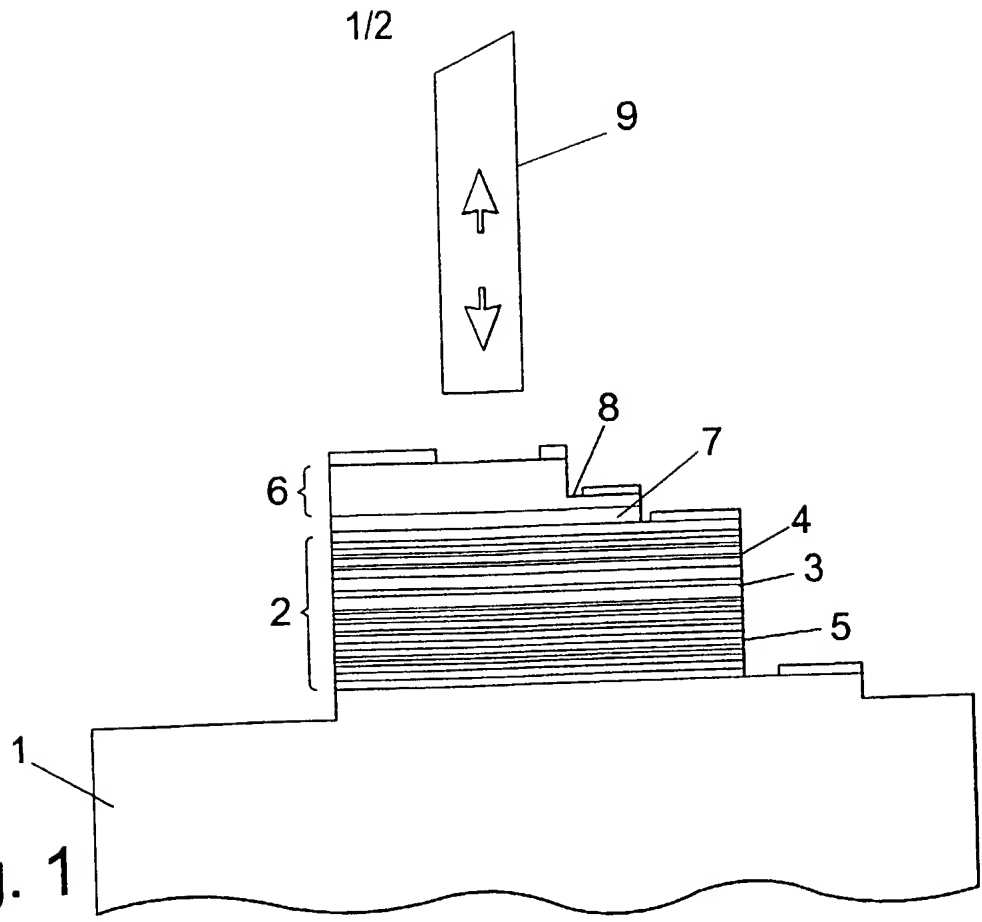
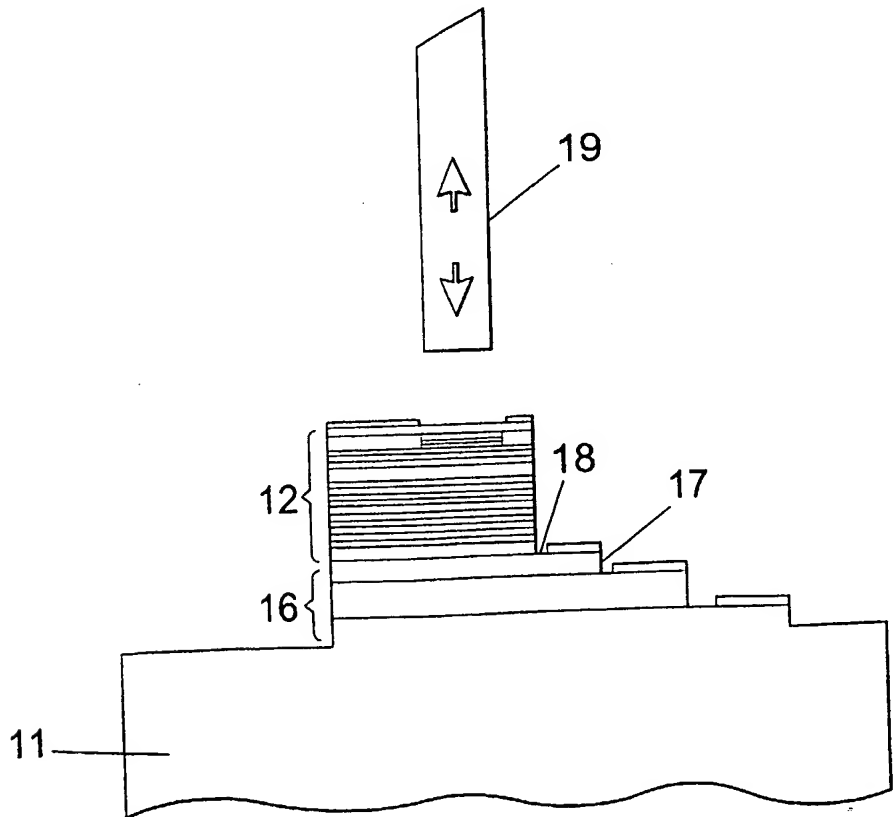


Fig. 2



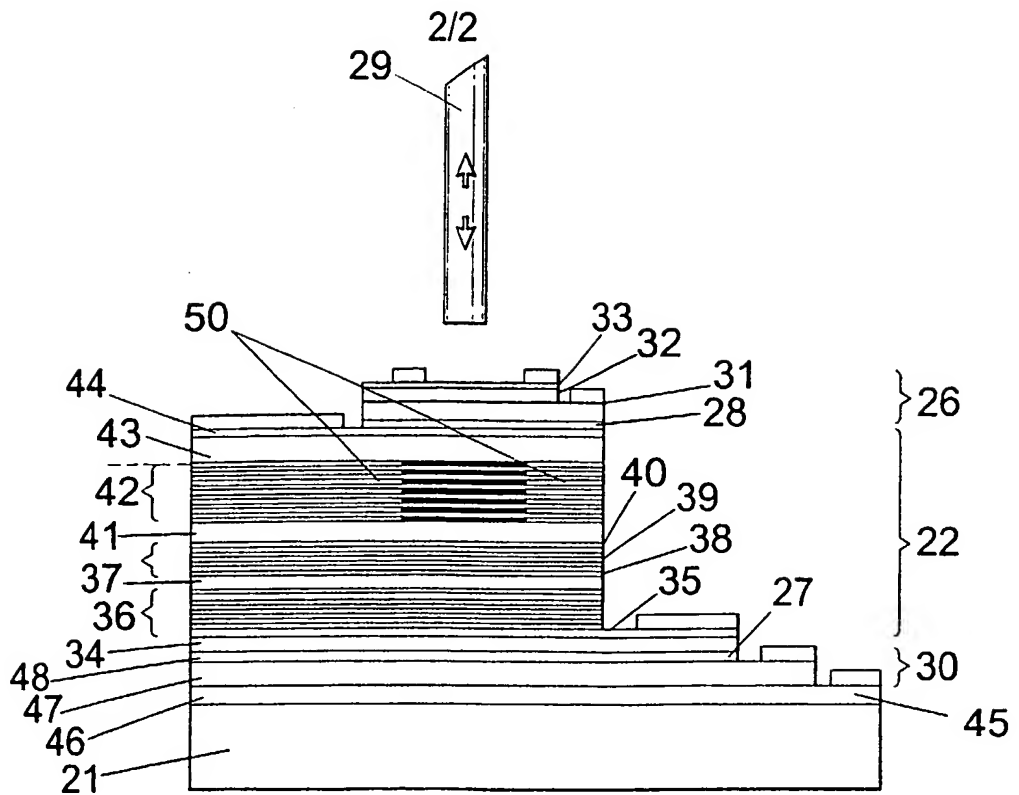


Fig. 3

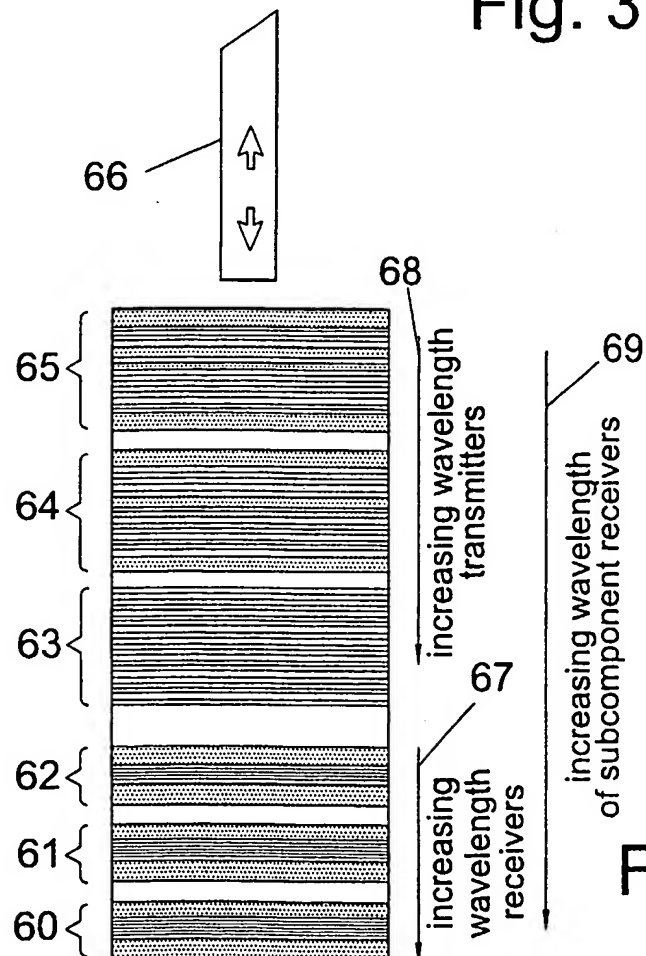


Fig. 4

# **“Optical Transceivers”**

This invention relates to optical transceivers and is concerned more particularly with integrated dual wavelength optical transceivers.

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It is known to produce dual wavelength optical transceivers within an integrated package permitting bidirectional optical communication over an optical fibre. For example, “Monolithically Integrated Low-Power Phototransceiver incorporating Microcavity LEDs and Multiquantum Well Phototransistors”, O. Qasimeh, Device  
10 Research Conference 2000, Conference Digest 58<sup>th</sup> DRC 2000, pages 175-176 discloses a GaAs-based HPT/MCLED low-power phototransceiver comprising a vertical cavity surface emitting laser (VCSEL) and a microcavity light-emitting diode (MCLED) fabricated side-by-side on a silicon substrate. VCSELs are particularly suitable in such applications as it is easy to design them to couple light efficiently to optical fibres by  
15 butt coupling. However, if the transmitted optical signal and the optical signal to be detected are to be transmitted over a single optical fibre, it is necessary to provide further optical components to couple both signals to the optical fibre.

It is also known to vertically integrate a VCSEL with a photodiode which serves  
20 to monitor the signal transmitted by the VCSEL by detecting light of the same wavelength as that transmitted by the VCSEL, as disclosed by “Monolithic Integration of Photodetector with Vertical Cavity Surface Emitting Laser”, G. Hasnain et al, Electronics Letters, vol. 27, no.18, pages 1630-1632, and “A Single Transverse Mode Operation of Top Surface Emitting Laser Diode with an Integrated Photodiode”, T. Kim  
25 et al, Lasers and Electro-Optics Society Annual Meeting Conference Proceedings, vol. 1, IEEE vol. 2, 1995, pages 416-417. However it has not previously been possible to provide a photodiode in such a structure which is capable of detecting an optical signal of a different wavelength received by the device along the same optical path as the transmitted signal.

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It is an object of the invention to provide a dual wavelength optical transceiver which is capable of bidirectional optical communication over a single optical fibre and which requires only a minimum number of optical components.

5        According to one aspect of the present invention there is provided an optical transceiver having an integrated structure comprising a substrate, an optical transmitting device on the substrate to transmit an optical signal of a first wavelength in a first direction along an optical path, and a reception photodetecting device integrated with the optical transmitting device on the substrate to detect an optical signal of a second  
10    wavelength, which is different to the first wavelength, travelling along the optical path in a second direction opposite to the first direction, wherein the optical transmitting device and the reception photodetecting device are positioned in sequence along the optical path and one of the devices is adapted to allow one of the optical signals to pass through the device in its passage along the optical path.

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The fact that the two devices are integrated in this manner, either by being grown on a common substrate or by flip-chip bonding, means that such an optical transceiver is capable of bidirectional optical communication over a single optical fibre without requiring the use of additional optical components to increase coupling  
20    efficiency to the optical fibre. This renders further components on the substrate unnecessary, and enables the device to be produced at very low cost. Previously proposed vertically integrated photodetectors have been restricted to single wavelength operation and are therefore unsuitable for single fibre bidirectional applications due to the fact that they would provide unacceptable crosstalk between the transmitted and  
25    received signals.

According to another aspect of the present invention there is provided a method of manufacturing an optical transceiver, the method comprising fabricating, on a substrate, an optical transmitting device and a reception photodetecting device such that,  
30    in operation, an optical signal of a first wavelength is transmitted by the optical transmitting device in a first direction along an optical path and an optical signal of a second wavelength, which is different to the first wavelength, travelling along the

optical path in a second direction opposite to the first direction is detected by the reception photodetecting device, the optical transmitting device and the reception photodetecting device being positioned in sequence along the optical path and one of the devices being adapted to allow one of the optical signals to pass through the device  
5 in its passage along the optical path.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:

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Figure 1 is a schematic vertical section through an exemplary embodiment of an optical transceiver in accordance with the invention;

Figure 2 is a schematic vertical section through an further exemplary  
15 embodiment of an optical transceiver in accordance with the invention;

Figure 3 is a schematic vertical section through a possible practical implementation of a further embodiment in accordance with the invention; and

20 Figure 4 is a schematic vertical section through a still further exemplary embodiment of an optical transceiver in accordance with the invention.

Referring to Figure 1 a first optical transceiver in accordance with the invention comprises a 1550 nm VCSEL 2 integrally fabricated on an InP substrate 1 and  
25 incorporating an active layer 3 positioned between two Bragg reflectors 4 and 5. A 1310 nm photodiode 6 is integrally fabricated on top of the VCSEL 2 with the interposition of an intermediate insulating layer 7 and a 1310 nm absorption layer 8 therebetween. The bandgap of the material of the VCSEL 2 is chosen to be active for light of 1550 nm wavelength, whereas the bandgap of the material of the photodiode 6  
30 is chosen to detect light of 1310 nm wavelength whilst being transparent to light of 1550 nm wavelength. Thus 1550nm light transmitted by the VCSEL 2 will pass through the photodiode 6 to be transmitted in a first direction along an optical path

defined by an optical fibre 9. Conversely 1310nm light travelling in a second direction, opposite to the first direction, along the optical path defined by the optical fibre 9 is received by the photodiode 6 before it can be absorbed by the absorption layer 8.

5 Referring to Figure 2 an alternative optical transceiver in accordance with the invention comprises a 1550 nm photodiode 16 integrally fabricated on an InP substrate 11 on top of a 1550 nm absorption layer. A 1310 nm VCSEL 12 is integrally fabricated on top of the photodiode 16 with the interposition of an intermediate insulating layer 17 and a 1310 nm absorption layer 18 therebetween. The bandgap of the material of the  
10 VCSEL 12 is chosen to be active for light of 1310 nm wavelength whilst being transparent to light of 1550 nm wavelength, whereas the bandgap of the material of the photodiode 16 is chosen to detect light of 1550 nm wavelength. Thus 1310 nm light transmitted by the VCSEL 12 will pass in a first direction along an optical path defined by an optical fibre 19, whereas 1550nm light travelling in a second direction, opposite  
15 to the first direction, along the optical path defined by the optical fibre 19 will pass through the VCSEL 12 before being received by the photodiode 16.

It should be noted that in the first embodiment the photodiode 6 must be placed closer to the optical fibre to prevent the 1310 nm light being absorbed by the layers in  
20 the VCSEL 2 before it can be detected by the photodiode 6, whereas, in the second embodiment, the VCSEL 12 must be placed closer to the optical fibre to prevent the 1310 nm light transmitted by the VCSEL 12 before absorbed by the photodiode 6. In each of the illustrated embodiments the optical fibre is shown as being positioned above the device, although it may be convenient in some applications for the optical fibre to be  
25 positioned on the substrate side of the device and for the chip to be flip bonded for electrical connections within its package.

In either of the above described embodiments a further photodiode may be integrated with the device in order to monitor the output optical power of the device.  
30 Such a monitor photodiode must of course be sensitive to the wavelength of the light transmitted by the VCSEL, and the most appropriate position for the monitor photodiode is immediately above or immediately below the VCSEL in the integrated

structure. In all the embodiments the photodiodes may be integrated with the VCSEL either monolithically or by bonding parts from different wafers together.

Figure 3 shows an embodiment incorporating a 1550 nm VCSEL 22, a 1310 nm  
 5 reception photodiode 26 and a 1550 nm monitor photodiode 30 for monitoring the  
 output optical power of the VCSEL 22. An optical fibre 29 is positioned to conduct the  
 transmitted and incoming signals in the same directions as in the embodiments of  
 Figures 1 and 2. The monitor photodiode 30 is integrally fabricated on the substrate 21,  
 and the VCSEL 22 is fabricated on top of the monitor photodiode 30 with the  
 10 interposition of an intermediate isolation layer 27 serving to reduce electrical crosstalk  
 between the VCSEL 22 and the monitor photodiode 30. The reception photodiode 26 is  
 fabricated on top of the VCSEL 22. The integrated  $\text{In}_{1-x}\text{Ga}_x\text{As}_y\text{P}_{1-y}$  structure may  
 comprise, by way of example, the following layers (with the specified dopings in  
 brackets) and with the specified bandgaps ( $\mu\text{m}$ ), considered in sequence working  
 15 upwardly from the substrate 21, which is preferably of InGaAsP with a lattice constant  
 of 5.9 Å:

Monitor photodiode etch stop layer 45 (p) 1.05  $\mu\text{m}$   
 Monitor photodiode anode layer 46 (p) 1.35  $\mu\text{m}$   
 20 Monitor photodiode active layer 47 (i) >1.55  $\mu\text{m}$   
 Monitor photodiode cathode layer 48 (n) 1.35  $\mu\text{m}$   
 Isolation layer 27 (i) 1.4  $\mu\text{m}$   
 VCSEL cathode layer 34 (n) 1.1  $\mu\text{m}$   
 VCSEL etch stop layer 35 (n) 1.05  $\mu\text{m}$   
 25 VCSEL Bragg reflector layers 36 (n) with 30 repeats of a sequence of 4 layers  
 having bandgaps 1.1, 1.2-1.1 graded, 1.2 and 1.1-1.2 graded respectively  
 VCSEL spacing layer 37 (i) 1.3  $\mu\text{m}$   
 VCSEL QW barrier layer 38 (i) 1.4  $\mu\text{m}$  with one repeat  
 VCSEL QW well layer 39 (i) 1.55  $\mu\text{m}$   
 30 VCSEL QW barriers layer 40 (i) 1.4  $\mu\text{m}$  with 4 repeats of the sequence of  
 layers 39 and 40  
 VCSEL spacing layer 41 (i) 1.3  $\mu\text{m}$



VCSEL Bragg reflector layers 42 (p) with 25 repeats of a sequence of 4 layers having bandgaps 1.1-1.2 graded, 1.1, 1.2-1.1 graded and 1.2 respectively

VCSEL anode 1 layer 43 (p) 1.2  $\mu\text{m}$  grown before proton implantation

VCSEL anode 2 layer 44 (p) 1.2  $\mu\text{m}$  grown after proton implantation

5 Isolation layer 28 (I) 1.38  $\mu\text{m}$

Receiver photodiode anode layer 31 (p) 1.1  $\mu\text{m}$

Receiver photodiode active layer 32 (i) 1.38  $\mu\text{m}$  – intermediate bandgap between transmit and receive wavelengths

Receiver photodiode cathode layer 33 (n) 1.1  $\mu\text{m}$

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The layers are shown in Figure 3 in the sequence in which they are grown or deposited with those areas of the layers being shown which are revealed by photolithography and selective etching. Contact regions and confinement regions are typically created by dry or plasma etching steps and by wet chemical steps. The crystal  
15 may be formed by metal-organic chemical vapour deposition (MOCVD) or by molecular beam epitaxy (MBE). The etchants can be chosen to provide etching selectivity, for example by using an etchant which etches InP at a faster rate than GaAs, thereby making it easier to stop an etch at a particular layer in the structure.. Furthermore proton implantation may be used in the regions 50 of the second Bragg  
20 reflector 42 to produce a single transverse mode, although oxide confinement layers may be used as an alternative to such an arrangement. Single transverse mode operation is only required if single mode optical fibre is used to increase the data rate-link span product.

25 The integrated  $\text{In}_{1-x}\text{Ga}_x\text{As}_y\text{P}_{1-y}$  structure can be lattice matched to the InP so that the atomic spacing of the quaternary compound is equal to the atomic spacing of the substrate. Lattice matching between all the layers prevents crystal dislocations and cracking due to internal stress.. Furthermore the bandgap of the quaternary compound can be varied between values corresponding to optical wavelengths from approximately  
30 920 nm to approximately 1730 nm. These values are calculated according to the following formulae:

Ga fraction for a crystal lattice matched to InP,  $x = (0.1894y)/(0.4184 - 0.013y)$

Bandgap of the compound,  $E_g = 1.347 - 0.778y - 0.149y^2$

Figure 4 shows a further embodiment of optical transceiver in accordance with the invention which is adapted to transmit and receive signals on different channels of different wavelengths. In this case the integrated structure comprises, in sequence beginning at the level of the substrate, a 1580 nm photodiode 60, a 1550 nm photodiode 61, a 1520 nm photodiode 62, a 1340 nm VCSEL 63, a 1310 nm VCSEL 64 and a 1280 nm VCSEL 65 for transmitting data at wavelengths of 1280 nm, 1310 nm and 1340 nm and for detecting data at wavelengths of 1520 nm, 1550 nm and 1580 nm along an optical path defined by an optical fibre 66. An arrow 67 denotes the direction of increasing detection wavelength of the photodiodes 60, 61 and 62, and an arrow 68 denotes the direction of increasing transmitting wavelength of the VCSELs 63, 64 and 65, whereas an arrow 69 denotes the overall direction of increasing wavelength of the subcomponents of the transceiver, the general principle being that the further the subcomponent is away from the optical fibre, the longer the wavelength at which it operates.

Clearly the invention is applicable to a transceiver having any number of receivers and any number of transmitters, and it is even possible to envisage the application of the invention to transceivers having a different number of receivers to the number of transmitters at a particular point in an optical network. For example, in a domestic application, it is possible that a user would require to receive more data than is transmitted and may therefore require a device with two receivers operating at different wavelengths and a transmitter operating at a third unique wavelength.

Clearly, in any such arrangement, it is necessary that the operating wavelengths of some of the subcomponents are such as to render each appropriate subcomponent transparent to light of the appropriate wavelengths which is to be allowed to pass through the subcomponent to one or more further subcomponents. As already demonstrated this can be achieved in a ternary/quaternary material system such as InGaAsP by controlling the material composition so as to vary the bandgap of each

subcomponent to absorb light at a given wavelength, but to allow longer wavelengths to pass through the subcomponent virtually unaffected.

5 It will be apparent to persons skilled in the art that many variations of the above described arrangements are possible to suit particular applications and materials, and all such variations are to be considered as being encompassed within the scope of the invention as defined by the accompanying claims. For example, it is possible to contemplate arrangements in which the devices are fabricated on substrates made of GaAs or sapphire, or on polymer substrates. Instead of all the devices being fabricated  
10 monolithically, it is also possible for the devices to be separately formed and for the different devices to be integrated by flip-chip bonding.

Furthermore it is envisaged that the invention can be applied to material systems which behave in a different way to bulk semiconductor or semiconductor quantum well  
15 optical systems previously referred to. For example, the invention may be applied to semiconductor quantum dot material systems or organic semiconductor material systems which do not necessarily exhibit absorption at all wavelengths above the minimum operating wavelength of the device. In such a system it is not necessary to order the subcomponents in terms of gradually increasing wavelength as the distance  
20 from the optical fibre increases. Instead the subcomponents can be positioned in any order provided that each subcomponent is transparent to the wavelengths associated with subcomponents further from the optical fibre.

As well as being applicable to vertically integrated devices, the invention is  
25 applicable to horizontal (planar) waveguide structures, such as systems based on organic semiconductor materials for which the manufacturing techniques are completely different to those for III-V semiconductor materials.

**CLAIMS:**

1. An optical transceiver having an integrated structure comprising a substrate, an optical transmitting device on the substrate to transmit an optical signal of a first wavelength in a first direction along an optical path, and a reception photodetecting device integrated with the optical transmitting device on the substrate to detect an optical signal of a second wavelength, which is different to the first wavelength, travelling along the optical path in a second direction opposite to the first direction, wherein the optical transmitting device and the reception photodetecting device are positioned in sequence along the optical path and one of the devices is adapted to allow one of the optical signals to pass through the device in its passage along the optical path.
2. An optional transceiver according to claim 1, wherein the reception photodetecting device is formed on top of the optical transmitting device and is adapted to allow the optical signal transmitted by the optical transmitting device to be transmitted through the reception photodetecting device.
3. An optical transceiver according to claim 1, wherein the optical transmitting device is formed on top of the reception photodetecting device and is adapted to allow the optical signal detected by the reception photodetecting device to travel through the optical transmitting device before being detected by the reception photodetecting device.
4. An optical transceiver according to claim 1, 2 or 3, wherein the optical transmitting device is a vertical cavity surface emitting laser (VCSEL).
5. An optical transceiver according to claim 1, 2 or 3, wherein the optical transmitting device is a light-emitting diode (LED).
6. An optical transceiver according to claim 4, wherein the optical transmitting device is a microcavity LED.

7. An optical transceiver according to any one of claims 1 to 5, wherein the reception photodetecting device is vertically integrated with the optical transmitting device on the substrate.
- 5 8. An optical transceiver according to any one of claims 1 to 5, wherein the reception photodetecting device is horizontally integrated with the optical transmitting device on the substrate.
9. An optical transceiver according to any preceding claim, further comprising an  
10 optical fibre for transmission of the optical signal transmitted by the optical transmitting device and the optical signal detected by the reception photodetecting device.
10. An optical transceiver according to claim 9, wherein the optical fibre is butt coupled to the substrate.
- 15 11. An optical transceiver according to any preceding claim, wherein a transmission photodetecting device is vertically integrated with the optical transmitting device on the substrate to detect the optical signal of the first wavelength transmitted by the optical transmitting device.
- 20 12. An optical transceiver according to any preceding claim, wherein the optical transmitting device is adapted to transmit an optical signal of 1310nm or 1550nm.
13. An optical transceiver according to any preceding claim, wherein the reception  
25 photodetector is adapted to detect an optical signal of 1310nm or 1550nm.
14. An optical transceiver according to any preceding claim, wherein an electrical isolation layer is provided between the optical transmitting device and the reception photodetecting device.
- 30 15. An optical transceiver according to any preceding claim, comprising at least one further optical transmitting device integrated with the first-mentioned optical

transmitting device to transmit an optical signal of a further wavelength different to the first and second wavelengths in the first direction along the optical path.

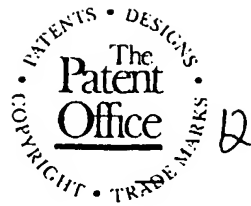
16. An optical transceiver according to any preceding claim, comprising at least one  
 5 further reception photodetecting device integrated with the first-mentioned reception photodetecting device to detect an optical signal of a further wavelength different to the first and second wavelengths travelling in the second direction along the optical path.

17. An optical transceiver according to any preceding claim, wherein the integrated  
 10 structure is an  $\text{In}_{1-x}\text{Ga}_x\text{As}_y\text{P}_{1-y}$  structure.

18. A method of manufacturing an optical transceiver, the method comprising fabricating, on a substrate, an optical transmitting device and a reception photodetecting device such that, in operation, an optical signal of a first wavelength is transmitted by  
 15 the optical transmitting device in a first direction along an optical path and an optical signal of a second wavelength, which is different to the first wavelength, travelling along the optical path in a second direction opposite to the first direction is detected by the reception photodetecting device, the optical transmitting device and the reception photodetecting device being positioned in sequence along the optical path and one of  
 20 the devices being adapted to allow one of the optical signals to pass through the device in its passage along the optical path.

19. An optical transceiver substantially or hereinbefore described with reference to the accompanying drawings.  
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20. A method of manufacturing an optical transceiver, the method being substantially or hereinbefore described with reference to the accompanying drawings.



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Application No: GB 0116982.0  
Claims searched: 1-20

Examiner: Stephen Brown  
Date of search: 29 October 2001

## Patents Act 1977 Search Report under Section 17

### Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK CI (Ed.S): H4B (BK24, BK24S)

Int CI (Ed.7): H04B: 10/24, 10/28; H01S: 5/026.

Other: Online : WPI, EPODOC, JAPIO

### Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	GB 2 243 720 A (AT&T) See especially the abstract, figure 2, and page 3, line 11, to page 5, line 33.	1-10, & 12-18
X	EP 0 512 556 A2 (NEC) See especially the abstract, figure 3, and column 4, line 33, to column 6, line 28.	1-13, & 15-18
X	WO 00/07052 A1 (Heidenhain) See especially the abstract and figure 1.	1-10, 12, 13, 15, 16 & 18
X	WO 99/43055 A1 (Siemens) See especially the abstract, figures 1-3, and page 10, line 28, to page 11, line 12.	1-10, & 12-18
X	WO 99/27663 A1 (Ericsson) See especially the abstract, figure 3, page 3, lines 24 to 27, and page 6, line 3, to page 7, line 14.	1-13, & 15-18
X	WO 98/31080 A1 (Gore) See especially the abstract, figures 1, 2, 4, 10, 11 & 12, page 2, lines 5 & 6, page 4, line 1, to page 6, line 27, page 12, lines 4 to 11, and page 13, line 34, to page 15, line 33.	1-10, & 12-18

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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Application No: GB 0116982.0  
Claims searched: 1-20

Examiner: Stephen Brown  
Date of search: 29 October 2001

Category	Identity of document and relevant passage	Relevant to claims
X	WO 96/31026 A1 (Whitaker) See especially the abstract, figure 3, and page 7, line 23, to page 8, line 27.	1-10, 12, 13, & 15-18
X	WO 96/17417 A1 (Hertz) See especially the abstract, figure 3, page 4, line 28, page 5, line 25, and page 7, line 30.	1-10, 12, 13, & 15-18
X	US 6 215 917 (Oki) See especially the abstract, figures 21, 22, 27, 28, 32 & 34, column 21, line 30, to column 22, line 14, column 25, line 35, to column 26, line 29, and column 27, lines 47 to 65.	1-13, & 15-18
X	US 6 148 015 (Alcatel) See especially the abstract and figure 1.	1-10, 12, 13, 15, 16, & 18
X	US 5 140 152 (University of Colorado) See especially the abstract, figure 2, column 4, line 51, to column 5, line 18, and column 6, lines 35 to 43.	1-10, 12, 13, 15, 16, & 18
X	US 4 730 330 (Siemens) See especially figure 1, column 5, lines 3 to 24, and column 6, lines 5 to 25.	1-10, 12, 13, & 15-18

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Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

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